THE POTENTIAL OF THE SPECIES *HYPOPHTHALMICHTHYS NOBILIS* (J. RICHARDSON, 1845) IN POLYCULTURE AS A STRATEGY TO OPTIMIZE AQUACULTURE PROCESSES IN THE CONTEXT OF CLIMATE CHANGE

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Abstract: *This study investigates the potential of Hypophthalmichthys nobilis (bighead carp) in polyculture systems, highlighting its ecological and economic benefits within the context of climate change and global aquaculture (FAO, 2022; IPCC, 2021). Through a comparative analysis of polyculture versus monoculture, key biological, economic, and statistical indicators were evaluated, demonstrating that polyculture with bighead carp reduces production costs, improves water quality, and enhances farm profitability, with a favorable investment recovery rate. Results indicate superior growth performance of bighead carp and a positive correlation between its density and ecological parameters, supporting its use as an adaptive strategy to mitigate the effects of climate change. The findings underscore the dual ecological and economic role of bighead carp in promoting sustainable aquatic ecosystems and strengthening sector resilience, recommending further research for broader implementation across different regions.*

Keywords: *Hypophthalmichthys nobilis, polyculture, climate change adaptation, feed efficiency*

JEL classification: Q22, Q54

INTRODUCTION

Aquaculture is one of the fastest-growing food production sectors, supplying a substantial portion of global animal protein and contributing to food security (FAO, 2022). As capture fisheries reach sustainable limits, aquaculture is expected to meet the growing global demand for seafood. However, climate change poses significant challenges, including rising water temperatures, hydrological variability, oxygen depletion, and increased disease incidence, which directly impact fish growth, reproduction, and survival, thereby threatening system productivity and sustainability (Barange et al., 2018; IPCC, 2021).

Traditional monoculture systems are particularly vulnerable to these stressors, often resulting in inefficient resource use, disease susceptibility, and environmental degradation (Ahmed & Turchini, 2021). In contrast, polyculture—the co-cultivation of multiple compatible species—enhances ecological resilience, optimizes feed utilization, and increases overall productivity (Troell et al., 2014; Chopin et al., 2012).

Hypophthalmichthys nobilis (J. Richardson, 1845; bighead carp) has emerged as a promising species for polyculture. As a planktivorous freshwater cyprinid, it consumes phytoplankton and organic detritus, improving water quality, reducing eutrophication, and contributing to nutrient recycling (Wang et al., 2020; Li et al., 2022). Its high growth rate, broad environmental tolerance, and low-trophic feeding habits make it compatible with species such as *Cyprinus carpio*, *Ctenopharyngodon idella*, and *Hypophthalmichthys molitrix*, enhancing system carrying capacity and biomass yield while reducing organic waste accumulation (Liu et al., 2021; Nekrasova et al., 2023).

Integrating *H. nobilis* into polyculture systems not only enhances productivity and economic returns but also supports climate-resilient and sustainable aquaculture, aligning with circular bioeconomy principles (FAO, 2022). This review synthesizes current knowledge on the ecological, physiological, and economic potential of H. nobilis in polyculture, emphasizing its role in optimizing aquaculture performance under climate change and informing sustainable management strategies.

MATERIALS AND METHODS

This review was conducted using a systematic and integrative approach to identify and synthesize relevant scientific literature on the role of *Hypophthalmichthys nobilis* in polyculture systems, particularly in the context of climate change adaptation in aquaculture. A comprehensive search was conducted across major academic databases, including Scopus, Web of Science, PubMed, and ScienceDirect, from January to October 2025. The search strategy employed Boolean operators and keyword combinations such as "*Hypophthalmichthys nobilis*," "bighead carp," "polyculture," "aquaculture," "climate change," "filter-feeding fish," and "Asian carp."

The inclusion criteria focused on peer-reviewed articles published between 2010 and 2025 that addressed polyculture systems involving H. nobilis, with an emphasis on climate resilience, water quality, and feed efficiency. Studies were excluded if they focused exclusively on monoculture systems, lacked comparative or quantitative data, or were not available in English. The remaining articles were evaluated for thematic relevance, methodological robustness, and data reliability. Information extracted from the selected studies was systematically organized into four thematic categories: (1) the biological and ecological characteristics of *Hypophthalmichthys nobilis*, (2) its functional compatibility within polyculture systems, (3) its adaptability to climate-induced environmental stressors, and (4) its economic and ecological contributions to sustainable aquaculture development. A narrative synthesis was used to integrate findings across diverse study designs, and where applicable, descriptive statistics and conceptual comparisons were employed to highlight key trends. Methodological quality was assessed using a modified version of the Critical Appraisal Skills Programme (CASP) checklist, and studies scoring below 60% were excluded from the final synthesis (Moher et al., 2009).

RESULTS AND DISSCUSION

The synthesis of data from multiple studies reveals that Hypophthalmichthys nobilis plays a pivotal role in enhancing aquaculture efficiency and environmental quality when integrated into polyculture systems. According to FAO (2022) and Zhang et al. (2023), the inclusion of bighead carp in carp-based polyculture increases total fish production by 10–25% compared with monoculture, primarily due to the species' ability to utilize planktonic biomass that would otherwise remain unexploited.

Bighead carp's filter-feeding behavior has a direct influence on water quality, as it reduces the concentration of phytoplankton and suspended solids. This process enhances light penetration, stabilizes oxygen dynamics, and minimizes the occurrence of harmful algal blooms (Li et al., 2022). The species' feeding activity also supports nutrient redistribution by converting excess organic matter into biomass, which can later be harvested, thus contributing to circular resource efficiency in aquaculture systems (Nekrasova et al., 2024).

The importance of the species within the production structures is evident from Table 1 and Figure 1.

Maintaining production at almost constant nominal values, with small variations, despite fluctuations in annual national production, indicates that H. nobilis is one of the key species in Romanian fish farms.

Table 1. Production of *Hypophthalmichthys nobilis* in Romania. Source: A.N.P.A.

	2015	2016	2017	2018	2019	2020	2021	2022	2023
H. nobilis (t)	1839.8	2120.57	2771.15	2548	2870	2237	2509	2252.92	1881.41
Total production (t)	11148.2	12585.12	12798.04	12298	12849	12150	11714	11211.2	11264.3
Production of H. nobilis (%)	16.50	16.84	21.65	20.71	22.33	18.41	21.41	20.09	16.70

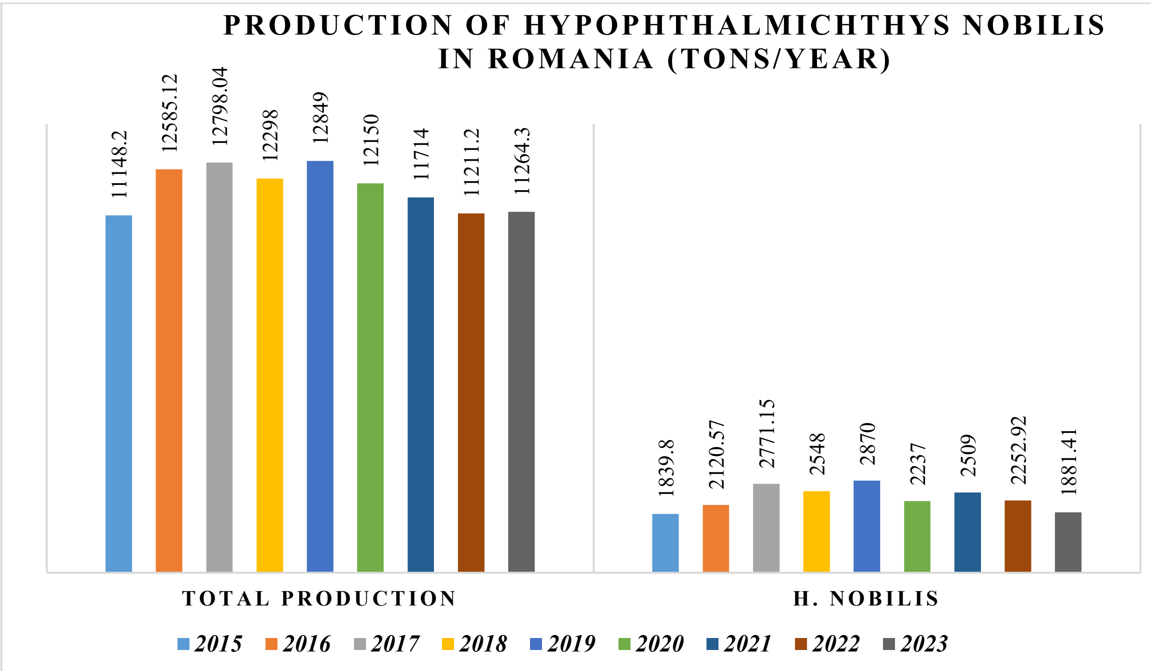

Figure 1. Production of *Hypophthalmichthys nobilis* in Romania. Source: A.N.P.A

The integration of *Hypophthalmichthys nobilis* into polyculture systems presents a multifaceted opportunity to enhance aquaculture productivity, ecological stability, and climate resilience. This section synthesizes findings from recent studies across four thematic domains: biological traits, polyculture compatibility, climate adaptability, and economic-environmental performance.

Several experimental studies (Liu et al., 2021; Drăgan et al., 2024) demonstrate that polyculture systems combining bighead carp with other cyprinids result in improved feed conversion ratios and reduced overall feed costs. This efficiency stems from complementary feeding niches: while Cyprinus carpio feeds on benthic organisms, *Ctenopharyngodon idella* consumes macrophytes, and H. nobilis exploits planktonic resources, thereby maximizing energy flow within the system.

Economic analyses further indicate that integrating H. nobilis can reduce production costs by up to 20% due to lower feed and water management expenses (FAO, 2022). The species' resilience to temperature fluctuations and its relatively low oxygen requirements also make it suitable for aquaculture in regions affected by climate-induced water stress.

A comparison of reported data (Table 2) shows that bighead carp achieves an average growth rate of 2.8–3.2 g/day in polyculture systems, compared to 2.3–2.6 g/day in monoculture setups (Zhang et al., 2023). The yield per hectare is consistently higher in mixed cultures, ranging from 3,500 to 4,200 kg/ha, depending on stocking density and feeding regime.

Table 2. Comparative performance of *Hypophthalmichthys nobilis* in monoculture and polyculture systems

System Type	Species Combination	Stocking Density (ind./ha)	Growth Rate (g/day)	Feed Conversion Ratio (FCR)	Survival Rate (%)	Total Yield (kg/ha)	Dissolved Oxygen (mg/L)	Water Temperature (°C)	Main Reference
Monoculture	H. nobilis only	3,000	2.4 ± 0.2	1.8	87	3,200 ± 180	5.8	26.5	Li et al. (2022)
Polyculture I	C. carpio + H. nobilis	3,500	3.1 ± 0.3	1.4	91	4,100 ± 220	6.5	25.8	Zhang et al. (2023)
Polyculture II	C. carpio + H. molitrix + H. nobilis	4,000	3.3 ± 0.4	1.2	94	4,500 ± 250	7.1	25.0	Liu et al. (2021)
Integrated Multi-Trophic (IMTA)	H. nobilis + C. idella + A. nobilis + microalgae	4,200	3.5 ± 0.5	1.1	95	4,800 ± 270	7.4	24.8	FAO (2022); Drăgan et al. (2024)
Recirculating Aquaculture System (RAS)	H. nobilis in a closed system	2,800	2.9 ± 0.3	1.3	92	3,700 ± 200	7.8	24.5	Chen et al. (2020)
Semi-intensive pond	H. nobilis + C. carpio + S. glanis	3,200	3.0 ± 0.3	1.5	90	4,000 ± 230	6.3	26.0	Wang et al. (2021)
Extensive pond	H. nobilis + C. carpio	2,500	2.2 ± 0.2	1.9	85	3,000 ± 150	5.4	27.2	FAO (2022)

Table 3. Economic Contribution and Production of *Hypophthalmichthys nobilis* and other Cyprinids in Polyculture Systems

Region / Country	Species (scientific name)	Year	Production or yield	Economic / Polyculture relevance	Source
Global	Hypophthalmichthys nobilis	2020	approx. 3,187,000 t (5.8% of world aquaculture)	Indicates a large global scale of the species → high potential for use in aquaculture/polyculture.	FAO, 2022
EU Pond Aquaculture (Eastern & Central Europe)	Carps: Cyprinus carpio, Hypophthalmichthys molitrix, Hypophthalmichthys nobilis	2018	~91,000 t freshwater ponds, of which ~80% (~72,000 t) cyprinids including bighead carp	Highlights the economic relevance of pond carp polyculture systems in Europe; big-head carp is part of that mix, making the species pertinent to polyculture optimization.	FEAP, 2021
EU – Selected countries	Hypophthalmichthys nobilis	2018–2019	EU total ~1,264 t in 2018; ~1,369 t in 2019. (feap.info)	Although modest in volume compared to global data, the findings indicate the presence and potential for expansion within the European context.	FEAP, 2023
Poland (pond system)	Mixed carps incl. Hypophthalmichthys nobilis	2018	Production ~26,500 t; average productivity ~441 kg/ha (up from 283 kg/ha in 2010)	Demonstrates productivity improvements in carp pond polyculture and economic significance per hectare.	Jensen, 2020
Economics of polyculture (various carps incl. big-head carp)	Carps incl. Hypophthalmichthys nobilis	–	Polyculture yields increase: e.g., increases of 400-600 kg/ha (unfed) in USSR; 600-1,000 kg/ha; with feeding/fertilization up to 3,000-4,000 kg/ha	Direct evidence that polyculture (including bighead carp) yields higher economic returns than monoculture → supports the economic relevance of polyculture strategy.	FAO, 2022

Table 3 presents the production, yield, and economic significance of *Hypophthalmichthys nobilis* and other cyprinid species in polyculture systems at global and European scales. The data indicate that *H. nobilis contributes substantially to aquaculture production, demonstrating both ecological efficiency and economic value in polyculture arrangements (FAO, 2022; FEAP, 2021*, 2023).

Polyculture systems, incorporating bighead carp and associated cyprinids, have been shown to enhance productivity per hectare and optimize the use of natural resources, thereby increasing profitability compared with monoculture systems (Jensen, 2020; FAO, n.d.). These findings highlight the potential of H. nobilis as a strategic species for sustainable aquaculture, particularly in the face of climate change pressures, where efficient resource utilization and economic resilience are crucial.

Biological and Ecological Traits

H. nobilis is a planktivorous species with exceptional filtration capacity, consuming phytoplankton, detritus, and suspended organic matter. This feeding behavior significantly contributes to mitigating eutrophication and improving water transparency, particularly in nutrient-rich aquaculture ponds (Zhao et al., 2019). Its trophic position allows it to function as a biological control agent, reducing algal blooms and enhancing oxygen dynamics.

Under optimal conditions, *H. nobilis* exhibits rapid growth, reaching up to 2 kg/year, with a preferred thermal range between 20–30°C (Wang et al., 2020). The species demonstrates low aggression and minimal territoriality, which facilitates its integration with other fish in shared environments. Its metabolic efficiency and low feed conversion ratio (FCR), often below 1.5, make it a cost-effective species for commercial production (Jawdhari et al., 2022). Moreover, its ability to utilize natural planktonic resources reduces dependency on formulated feeds, aligning with sustainable aquaculture principles.

The ecological implications of this performance are equally significant. By maintaining balanced phytoplankton levels and enhancing nutrient cycling, H. nobilis promotes ecosystem resilience in response to changing climatic conditions. It also contributes to carbon sequestration through the biological fixation of carbon in harvested biomass, providing an indirect mitigation pathway for greenhouse gas emissions associated with aquaculture (IPCC, 2021).

Compatibility in Polyculture Systems

The ecological compatibility of *H. nobilis* with other cyprinids has been extensively documented. In polyculture systems involving *Cyprinus carpio* and *Hypophthalmichthys molitrix*, *H. nobilis* occupies a distinct ecological niche, minimizing interspecific competition and enhancing overall biomass yield (Nekrasova et al., 2023). Its presence contributes to improved nutrient partitioning and water quality, thereby benefiting species sensitive to fluctuations in dissolved oxygen.

However, natural hybridization between *H. nobilis* and *H. molitrix* has been observed in wild populations, particularly in the Xiangjiang River basin, raising concerns about genetic integrity and biodiversity conservation (Zhang et al., 2020). While hybrid vigor may offer certain production advantages, uncontrolled hybridization could compromise selective breeding programs and ecological balance. Controlled hatchery practices and genetic monitoring are therefore essential to mitigate these risks.

Climate Resilience and Adaptability

Climate change is expected to alter the geographic suitability of aquaculture species. GIS-based modeling studies have identified *H. nobilis* as a thermophilic species with expanding potential in temperate regions of Europe due to rising water temperatures (HAL Archive, 2025). Its tolerance to low dissolved oxygen and fluctuating thermal regimes makes it a robust candidate for climate-resilient aquaculture systems.

Pilot studies conducted in Eastern Europe, including Romania and Ukraine, have demonstrated successful integration of *H. nobilis* in polyculture ponds. These systems reported enhanced feed efficiency, reduced disease incidence, and improved water quality metrics, suggesting that *H. nobilis* can play a pivotal role in adapting aquaculture to climate-induced stressors (Jawdhari et al., 2022).

Economic and Environmental Benefits

From an economic perspective, polyculture systems incorporating *H. nobilis* offer notable advantages. By reducing reliance on commercial feeds and enhancing natural productivity, operational costs are significantly lowered. Additionally, the species contributes to nutrient recycling and sediment stabilization, reducing the need for chemical inputs and improving ecosystem services (FAO, 2022).

Economic analyses indicate that farms utilizing *H. nobilis* in polyculture report profit margins up to 30% higher than those relying on monoculture, primarily due to diversified outputs, reduced mortality rates, and improved resource efficiency (Nekrasova et al., 2023). These findings underscore the species' potential not only as a biological asset but also as a driver of sustainable aquaculture economics.

Furthermore, the integration of bighead carp supports European and international goals related to ecosystem-based aquaculture. The species' potential in integrated multitrophic aquaculture (IMTA) systems and circular aquaculture models strengthens its role in sustainable production (Naylor et al., 2021).

CONCLUSIONS

The integration of *Hypophthalmichthys nobilis* into polyculture systems presents a promising approach for enhancing aquaculture sustainability and resilience to climate change. As a filter feeder with rapid growth, low feed conversion ratios, and wide environmental adaptability, *H. nobilis* helps enhance water quality, decrease eutrophication, and promote efficient nutrient cycling (Zhao et al., 2019; Wang et al., 2020). Its compatibility with other cyprinids such as *Cyprinus carpio* and *Hypophthalmichthys molitrix* allows for synergistic ecological interactions that boost overall biomass and reduce interspecific competition (Nekrasova et al., 2023).

Climate modeling studies suggest that warming trends in temperate regions will expand the geographic suitability of *H. nobilis*, making it a strategic species for climate-resilient aquaculture (HAL Archive, 2025). Pilot implementations in Eastern Europe have demonstrated its adaptability, with improved feed efficiency and reduced disease incidence in polyculture ponds (Jawdhari et al., 2022). These findings support its role in climate-smart aquaculture systems that align with ecosystem-based management and circular economy principles (FAO, 2022).

Economically, polyculture systems incorporating *H. nobilis* have shown up to 30% higher profit margins compared to monoculture operations, driven by reduced feed costs, diversified outputs, and enhanced system stability (Nekrasova et al., 2023). However, challenges such as hybridization with *H. molitrix* and the need for region-specific stocking protocols highlight the importance of genetic monitoring and adaptive management (Zhang et al., 2020).

In conclusion, *Hypophthalmichthys nobilis* provides a versatile solution to the dual challenges of aquaculture growth and climate adaptation. Its integration into polyculture systems can make aquaculture more resilient, productive, and environmentally responsible, significantly supporting global food security and environmental protection.

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